North Slope of Alaska Gas Hydrate Test Well Program

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Introduction

Gas hydrates are crystalline substances composed of water and gas, in which a solid water-lattice accommodates gas molecules in a cage-like structure, or clathrate. Gas hydrates are widespread in permafrost regions and beneath the sea in sediment of outer continental margins. While methane, propane, and other gases can be included in the clathrate structure, methane hydrates appear to be the most common in nature. The amount of methane sequestered in gas hydrates worldwide is probably enormous, but estimates of the amounts are speculative and range over three orders-of-magnitude, from about 100,000 to 270,000,000 trillion cubic feet (modified from Kvenvolden, 1993). The estimated amount of gas in the hydrate reservoirs of the world greatly exceeds the volume of known conventional gas reserves. The production history of the Russian Messoyakha gas hydrate field demonstrates that gas hydrates are an immediate source of natural gas that can be produced by conventional methods (Collett, 1993b).

Even though gas hydrates are known to occur in numerous arctic and marine sedimentary basins, little is known about the geologic parameters controlling their distribution. Most of the published gas hydrate resource estimates have of necessity been made by broad extrapolation of general knowledge of local geologic conditions (Kvenvolden, 1993). The primary objectives of this study are to determine the volume of natural gas stored within the gas hydrate accumulations of northern Alaska and to assess the availability and production potential of gas hydrates in Alaska.

Gas Hydrate Technical Review

Under appropriate conditions of temperature and pressure (Sloan, 1990), gas hydrates usually form one of two basic crystal structures known as Structure-I and Structure-II. Each unit cell of Structure-I gas hydrate consists of 46 water molecules that form two small dodecahedral voids and six large tetradecahedral voids. Structure-I gas hydrates can only hold small gas molecules such as methane and ethane, with molecular diameters not exceeding 5.2 angstroms. The unit cell of Structure-II gas hydrate consists of 16 small dodecahedral and 8 large hexakaidecahedral voids formed by 136 water molecules. Structure-II gas hydrates can contain gases with molecular dimensions in the range of 5.9 to 6.9 angstroms, such as propane and isobutane. At conditions of standard temperature and pressure (STP), one volume of saturated methane hydrate (Structure-I) will contain as much as 164 volumes of methane gas — because of this large gas-storage capacity, gas hydrates are thought to represent an important source of natural gas.

On a macroscopic level, many of the gas hydrate mechanical properties resemble those of ice, because hydrates contain a minimum of 85 percent water on a molecular basis. Among the exceptions to this heuristic is thermal conductivity, which is relatively low in hydrates; this can be attributed to the molecular structural differences between ice and hydrates. Of interest are the phase-equilibrium properties of gas hydrates, which are mostly controlled by the fit of the guest gas molecules within the hydrate water cages. For example, the addition of propane to a pure methane hydrate changes the hydrate structure (Structure-I >> Structure-II) and broadens the conditions in which the hydrates can occur. For a complete description of the structure and properties of hydrates see the summary by Sloan (1990).

Onshore gas hydrates are known to be present in the West Siberian Basin (Makogon and others, 1972) and are believed to occur in other permafrost areas of northern Russia, including the Timan-Pechora province, the eastern Siberian Craton, and the northeastern Siberia and Kamchatka areas (Cherskiy and others, 1985). Permafrost-associated gas hydrates are also present in the North American Arctic. Direct evidence for gas hydrates on the North Slope of

Alaska comes from a core-test, and indirect evidence comes from drilling and open-hole well logs that suggest the presence of numerous gas hydrate layers in the area of the Prudhoe Bay and Kuparuk River oil fields (Collett, 1983; Collett, 1993a). Well-log responses attributed to the presence of gas hydrates have been obtained in about one-fifth of the wells drilled in the Mackenzie Delta, and more than half the wells in the Arctic Islands are inferred to contain gas hydrates (Judge, 1988; Judge and Majorowicz, 1992). The combined information from arctic gas-hydrate studies shows that, in permafrost regions, gas hydrates may exist at subsurface depths ranging from about 130 to 2,000 m (Kvenvolden, 1988). Because gas hydrates are widespread in permafrost regions, they may be a potential energy resource. World estimates for the amount of natural gas in permafrost-associated gas hydrate deposits range from 5.0×10^2 to 1.2×10^6 trillion cubic feet (TCFG) for permafrost areas (adapted from Kvenvolden, 1993).

North Slope Gas Hydrate Assessment

One of the major goals of this study is to estimate the gas-hydrate resources in northern Alaska. Similar to the assessment of the conventional resources in the 1995 U.S. Geological Survey (USGS) National Oil and Gas Assessment (Gautier and others, 1995), this appraisal of gas hydrates is based on a play-analysis scheme. We have defined, described, and assessed all the gas-hydrate plays in northern Alaska regardless of their current economic or technological status. Therefore, this assessment is concerned with the *in-place* gas hydrate resources—that is, the amount of gas that may exist within the gas hydrates without reference to its recoverability. In a play analysis method, prospects (potential hydrocarbon accumulations) are grouped according to their geologic characteristics into plays. The geologic settings of the hydrocarbon occurrences in the play are then modeled. Probabilities are assigned to the geologic attributes of the model necessary for generation and accumulation of hydrocarbons. In this appraisal method, geologists make judgments about the geologic factors necessary for the formation of a hydrocarbon accumulation and quantitatively assess the geologic factors that determine its size. For this gas hydrate assessment, a play consists of a single prospect (prospect = play). This assumption has been made due to the relative lack of knowledge pertaining to individual gas-hydrate accumulation sizes and distribution.

In this assessment (Collett, 1995), two gas-hydrate plays were identified; for each play, in-place gas hydrate resources were estimated. Estimates for each of the plays were aggregated to produce the estimate of total gas-hydrate resources in northern Alaska. In the following section, the Alaska gas hydrate province is described. Following the province description is a systematic discussion of the individual gas hydrate plays within the province. Each play description includes a play map that shows the play limits and the thickness of the gas-hydrate stability zone. Also included is an estimate of in-place natural gas-hydrate resources.

The Alaska gas hydrate province extends 950 km from the Chukchi Sea on the west to the Canadian border on the east. Its maximum width is about 320 km. The total area of the province is about 140,000 km^2. The geology and petroleum geochemistry of the rocks in northern Alaska are described in detail in a number of publications (Lerand, 1973; Grantz and others, 1975; Carman and Hardwick, 1983; Bird and Magoon, 1987; and Gryc, 1988). The sedimentary rocks of northern Alaska can be conveniently grouped into three sequences that indicate major episodes in the tectonic development of the region and, to a degree, its lithologic character. Defined on the basis of source area, these sequences, proposed by Lerand (1973) and applied to northern Alaska by Grantz and others (1975) are, in ascending order, the Franklinian (Cambrian through Devonian), the Ellesmerian (Mississippian to lower most Cretaceous), and the Brookian (Lower Cretaceous to Holocene).

The only direct confirmation of natural-gas hydrates in the Alaska gas hydrate province was obtained in 1972 when ARCO and EXXON successfully recovered a core containing gas hydrates (reviewed by Collett, 1993a). Well-log data from an additional 445 Alaska wells were examined for possible gas-hydrate occurrences (Collett, 1993a). This review of all available data revealed that gas hydrates are inferred to occur in 50 of the surveyed wells. Many of these wells have multiple gas-hydrate-bearing units, and individual occurrences range from 3 to 31 m thick. The well-log inferred gas hydrates occur in six laterally continuous sandstone and conglomerate units and are geographically restricted to the east end of the Kuparuk River production unit and the west end of the Prudhoe Bay production unit (figs. 1 and 2). Open-hole logs from wells in the west end of the Prudhoe Bay field also indicate the presence of a large free-gas accumulation trapped stratigraphically downdip below four of the log-inferred gas hydrates. The potential in-place volume of gas within the log-inferred gas hydrates (exclusive of the associated free-gas) of the Prudhoe Bay-Kuparuk River area is approximately 37 to 44 trillion cubic feet (at STP) [approximately 1.0×10^{12} to 1.2×10^{12} cubic meters of gas] (Collett, 1993a).

Two plays (fig. 3) were defined and individually assessed within the Alaska gas hydrate province: (1) Topset play and (2) Fold Belt play.

Topset Play

The Topset play (fig. 3) consists of stratigraphic traps and sandstone reservoirs of Cretaceous and Tertiary age and includes those rocks represented on seismic records in the topset position of a clinaform sequence. This play is limited to the relatively undeformed rocks north of the Brooks Range fold belt. These rocks, the Nanushuk Group and Sagavanirktok Formation, consist of marine and nonmarine deltaic sandstone, siltstone, shale, conglomerate, and coal.

The methane-hydrate stability zone in this play reaches a maximum thickness of about 1,000 m within the area of the Prudhoe Bay field. The northern offshore limit of the hydrate stability zone corresponds with the 50-m bathymetric contour.

Reservoir rocks consist of sandstone and conglomerate and may comprise as much as 75 percent of the total thickness of the gas-hydrate stability zone, even though individual beds seldom exceed 20 m. Fair to good reservoir continuity is expected, but marked changes may occur over short distances.

Potential source rocks within the play interval are interbedded deltaic shales and mudstones, which are immature. Beneath the methane-hydrate stability zone are numerous potential thermally mature gas sources, some of which have contributed to the known gas-hydrate accumulations in the Prudhoe Bay-Kuparuk River area.

Postulated traps are mostly stratigraphic and are related to facies changes, or traps formed against small-displacement normal faults. Faults and interbedded shales are expected to provide only fair to poor conventional seals.

This play includes onshore State lands and offshore State and Federal waters. The gas-hydrate resource estimate for this play is divided into two parts, with one estimate representing the hydrate resources within the State lands and waters and the second representing the offshore Federal hydrate resources.

Fold Belt Play

The Fold Belt play (fig. 3) consists of anticlinal traps in Cretaceous and Tertiary sandstone reservoirs in the northern part of the Brooks Range fold belt. The play is situated north of the Brooks Range thrust belt and south of undisturbed deposits of the Topset play; its western border is the Chukchi Sea; its eastern border extends offshore to the 50-m bathymetric contour in the Beaufort Sea. In the eastern part, this play encompasses rocks of the Sagavanirktok and Canning Formations, Hue Shale, pebble shale unit, and Kemik Sandstone; in the western part of the play, it includes parts of the Nanushuk Group and Torok Formation.

The methane-hydrate stability zone in this play reaches a maximum thickness of about 500 m in the north-central portion of the play area, and thermal conditions preclude the occurrence of gas hydrates in about half of the play.

Potential reservoirs are sandstone units, representing deltaic and shallow-marine environments. Sandstone porosities are expected to range from about 5 to 20 percent.

Potential source rocks include gas-prone shale units of the Nanushuk Group and the Sagavanirktok, Torok, and Canning Formations. Gas-prone source rocks within the play range from immature to mature.

Conventional traps within this play consist of fault-cored anticlines related to Brooks Range thrusting. Stratigraphic traps, such as updip pinchouts on the flanks of anticlines, may also be present. Shales are expected to provide fair to good seals, although the effectiveness of these seals may be reduced by faulting.

This play includes onshore State lands and offshore State and Federal waters. The gas-hydrate resource estimate for this play is divided into two parts, with one estimate representing the hydrate resources within the State lands and waters and the second representing the offshore Federal hydrate resources.

Gas Hydrate Resource Summary

The estimates of in-place gas-hydrate resources included in this report are presented in the form of complementary cumulative probability distribution (fig. 4). This distribution summarizes the range of estimates generated by the FASPU computer program (Crovelli and Balay, 1990) as a single probability curve in a “greater than” format (fig. 4). Our estimates are reported at the mean and at the 95th, 75th, 50th, 25th, and 5th fractiles. We consider the 95th and 5th fractiles to be “reasonable” minimum and maximum values, respectively

In-place gas resources within the gas hydrates of northern Alaska are estimated to range from 236 to 2,357 trillion cubic feet of gas (TCFG) [6.7 to 66.8 trillion cubic meters of gas (TCMG)], at the 0.50 and 0.05 probability levels, respectively (fig. 4). Although these ranges of values show a high degree of uncertainty, they do indicate the potential for enormous quantities of gas stored as gas hydrates. The mean in-place value for the entire North Slope is calculated to be 590 trillion cubic feet of gas (TCFG) [16.7 trillion cubic meters of gas (TCMG)]. This assessment of in-place gas hydrates represents those deposits that constitute the resource base without reference to recoverability.

Gas Hydrate Test Well

Most recently the U.S. Geological Survey has been involved in the development of a multi-component industry/government supported gas hydrate research coring and production testing project in northern Alaska. This proposed project is designed to study scientific and engineering properties of gas hydrates in the Western Operating Area of the Prudhoe Bay Field. Potential participants include: the Japan National Oil Corporation, the Japan Petroleum Exploration Co., Ltd., the Geological Survey of Canada, the United States Geological Survey, and the University of Alaska at Fairbanks. The project, planned to begin January, 1998, will involve drilling of (1) an industry well designed primarily to test and evaluate a number of newly-developed engineering technologies, and (2) a continuously cored slim well designed to provide a basis for comparing the effectiveness of these technologies. A multidisciplinary (geology, geophysics, geochemistry, drilling, production and reservoir engineering) science project will be undertaken to establish the physical characteristics of in-situ gas hydrates and assess the regional geologic conditions at the site.

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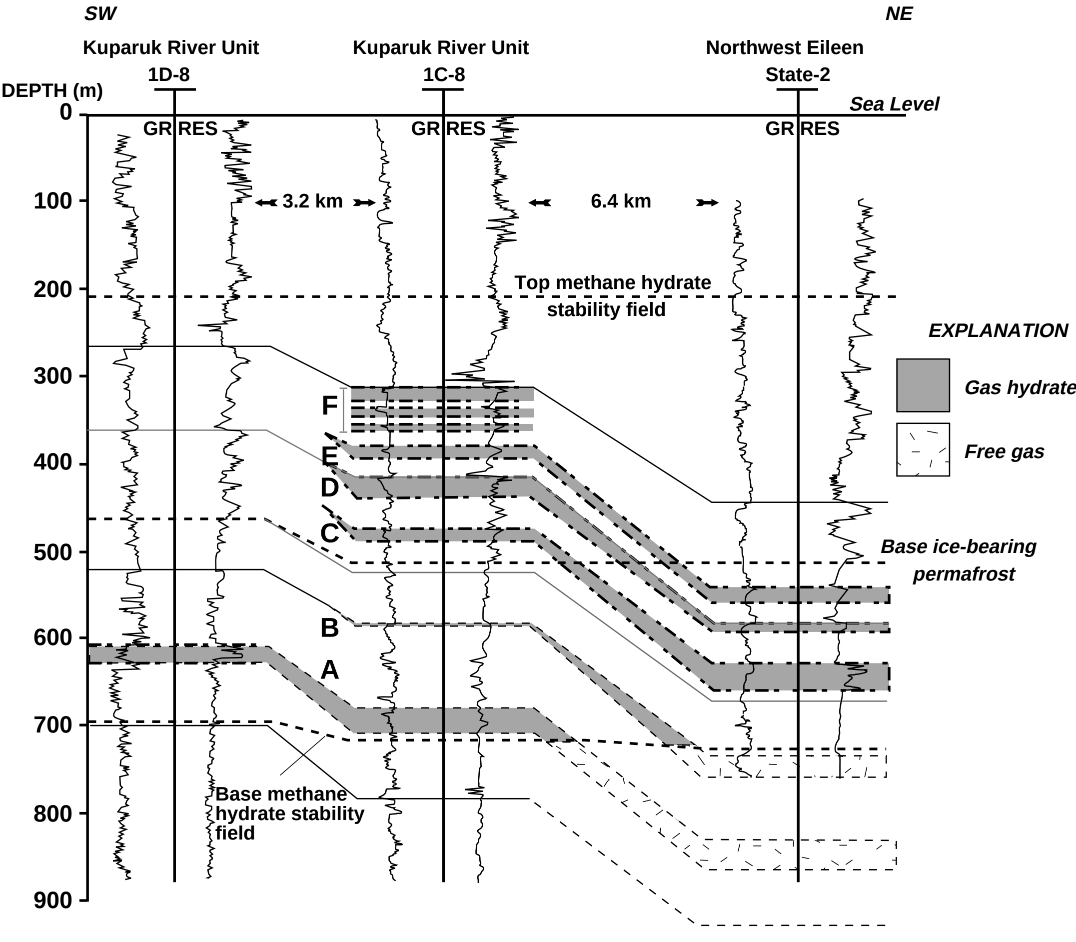

Figure 1. Cross section showing the laterial and vertical extent of gas hydrates and underlying free-gas occurrences in the Prudhoe Bay-Kuparuk River area (modified from Collett, 1993a). See figure 2 for location of cross section. The gas-hydrate-bearing units are identified with the reference letters A-F. The solid lines are log correlation markers used to construct the regional stratigraphic framework. Correlation markers are dashed where uncertain.

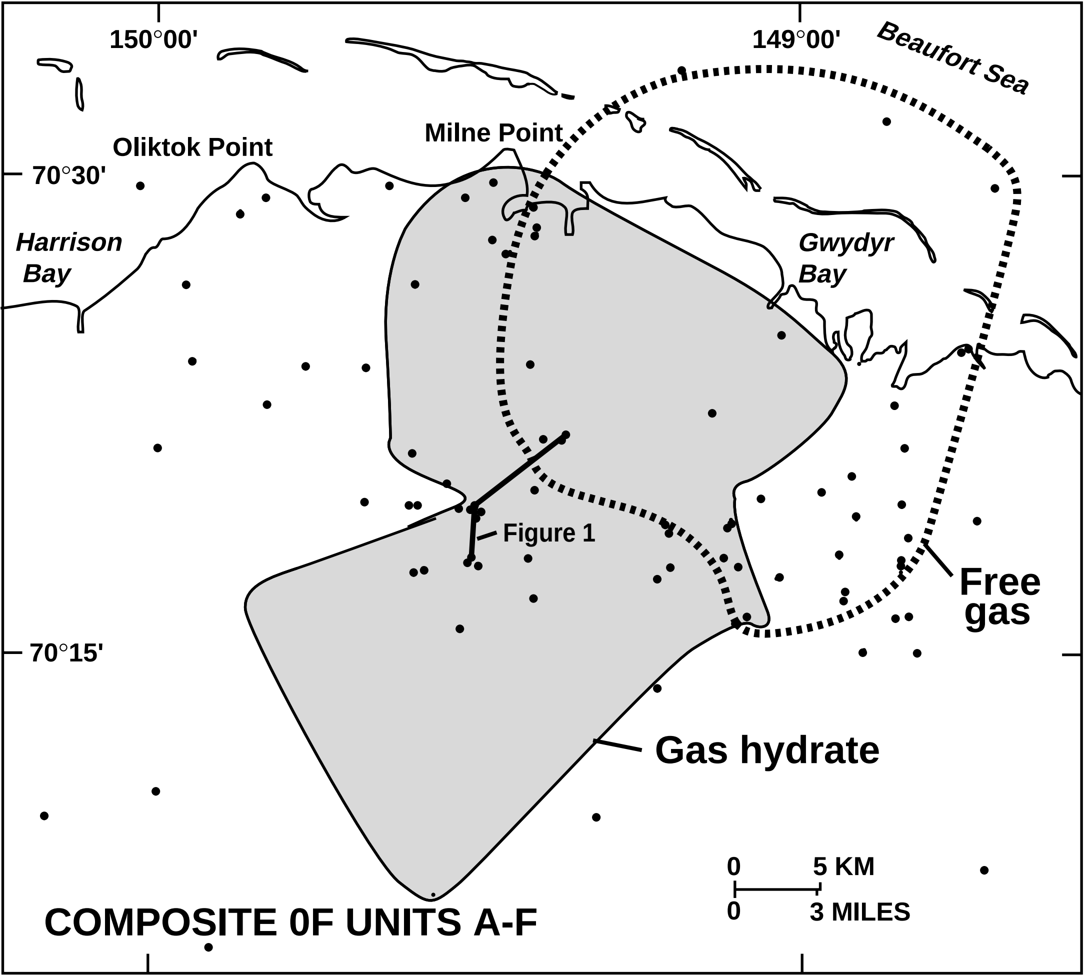

Figure 2. Composite map of all six gas-hydrate/free-gas units (A-F) from the Prudhoe Bay-Kuparuk River area (modified from Collett, 1993a). Dots show well locations.

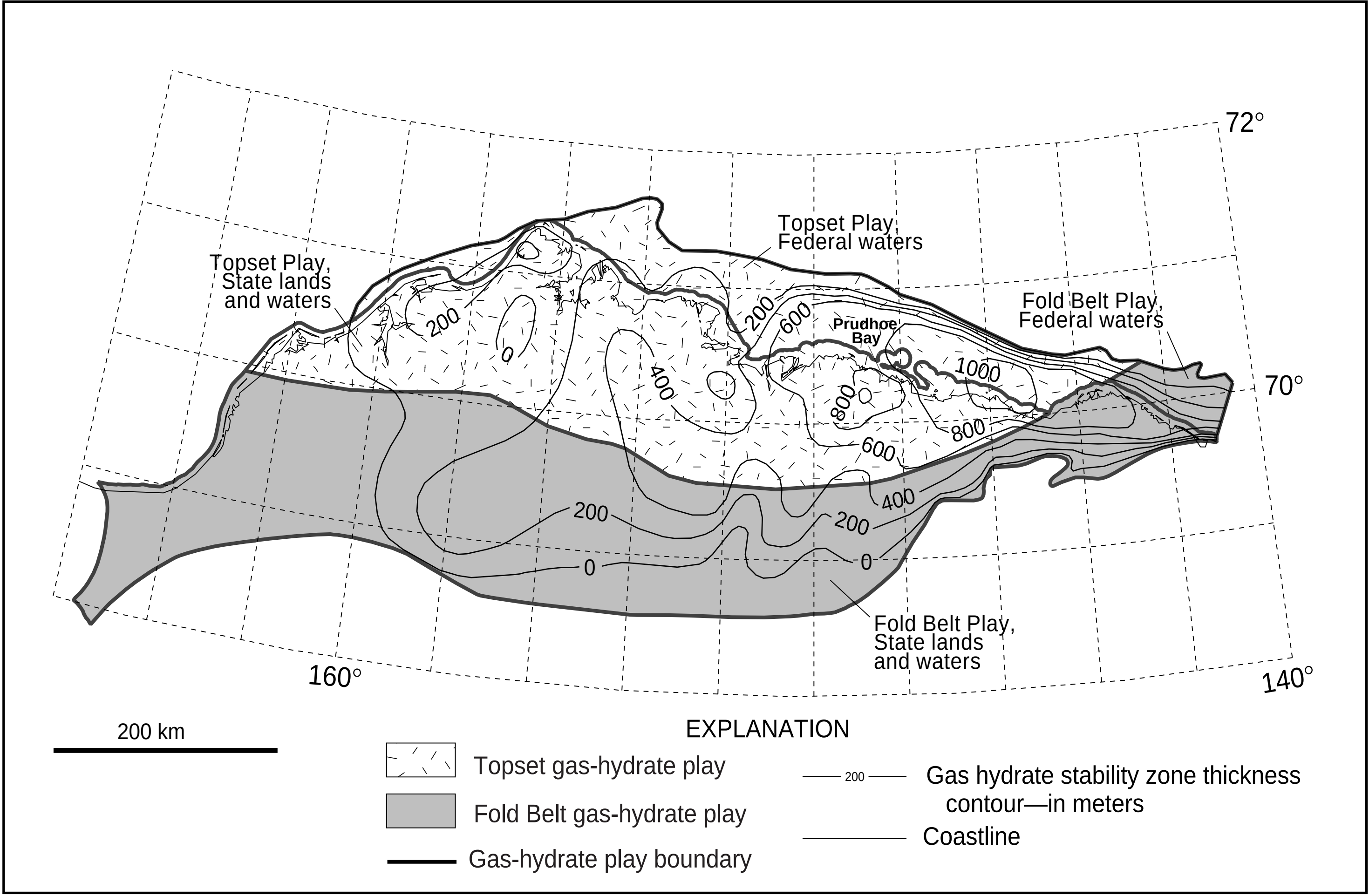

Figure 3. Map of the Alaska Topset and Fold Belt gas-hydrate plays (modified from Collett, 1995).

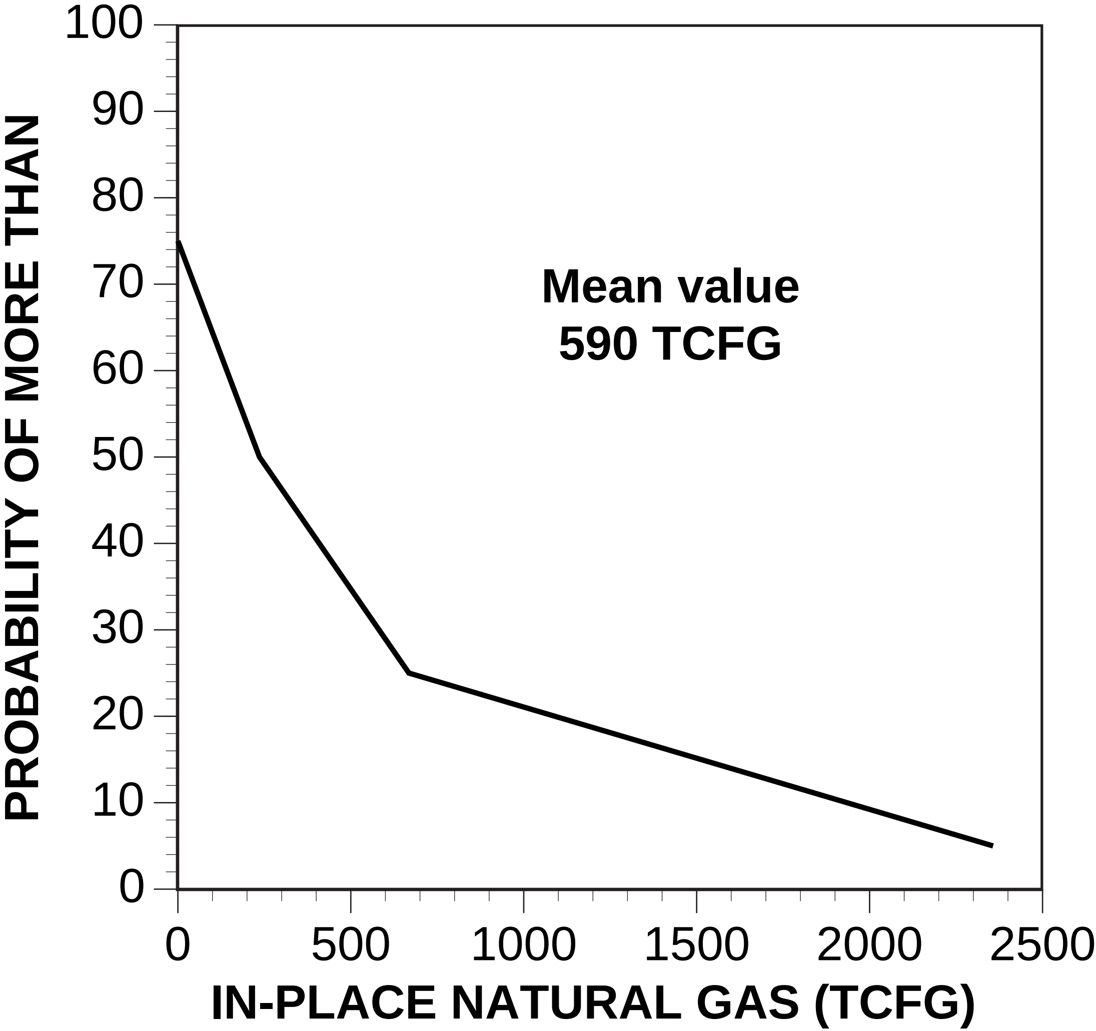

Figure 4. Cumulative probability curve showing the estimated in-place gas resources within the gas hydrates of northern Alaska. The curve is read as follows: there is a 50 percent chance that the gas hydrate resource is greater than 236 trillion cubic feet of gas (TCFG), and there is a 5 percent chance that the gas hydrate resource is greater than 2,357 trillion cubic feet of gas (TCFG) (modified from Collett, 1995).